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Electrooptic Effect of Thick Freely Suspended Ferroelectric Liquid Crystal Film

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Freely suspended (FS) ferroelectric liquid crystal (FSFLC) film has attracted much attention as a thin two-dimensional liquid crystal system,[1-4] because it has layered structure and its thickness can be varied from only two layers to several thousands layers. In the FS film, molecules are not influenced by substrates of a conventional cell, so that several characteristic properties have been observed.[5-7] In this paper, a characteristic electrooptic effect of the FS film which has the helicoidal structure is studied.

Ferroelectric liquid crystal (Chisso, CS-1029) is used in this study. This sample has chiral smectic C phase between -18 and 72.9 ℃. A spontaneous polarization Ps and a helical pitch are 41.3 nC/cm^2 and 2 μm at 25 ℃, respectively. All experiments were carried out at 35 ℃.

The FS film was prepared across two metal blades. Two polyethyleneterephthalate (PET) sheets were set between the blades. The sample was loaded in the square free area surrounded by the blades and PET sheets. One of the PET sheets can slide along the blade to expand the FS film. These blades were also used as electrodes to apply an electric field to the FS film. The distance between the electrodes was 3 mm and the expanded square area was 9 mm^2. The FS film was horizontally settled on an optical bench.

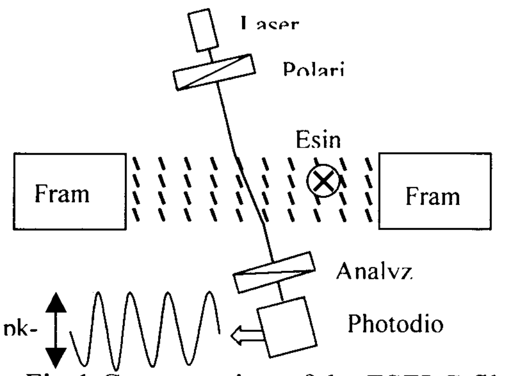


Fig.1 Cross-section of the FSFLC film and experimental setup.

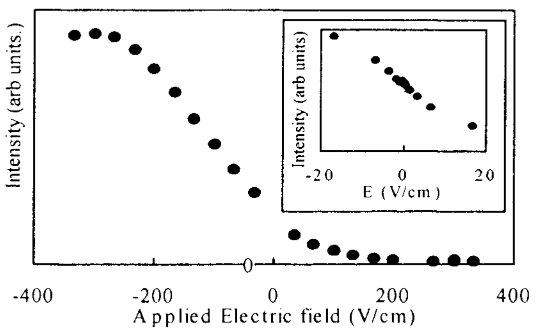


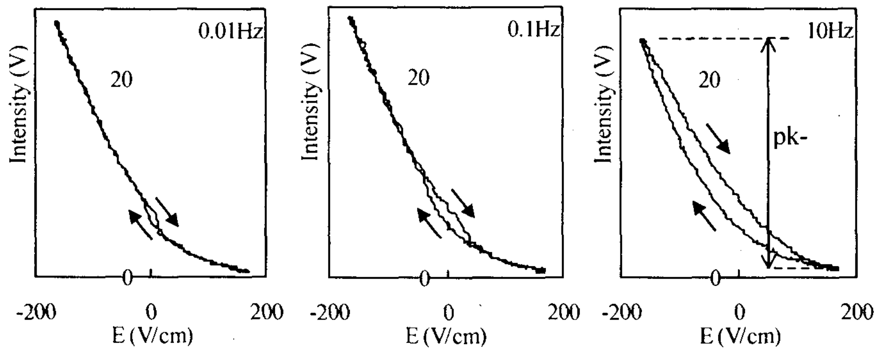
Fig.2 Applied field dependence of the light intensity.

In the freely suspended ferroelectric liquid crystal (FSFLC) films, smectic layers are parallel to the film surface, so that the molecules can be oriented around the axis perpendicular to the film with keeping constant tilt angle. A semiconductor laser beam (λ = 670 nm) which was perpendicular to the applied field impinged on the FS film with incident angle of 12.6° , after passing through a polarizer, as shown in Fig.1. The polarizer was adjusted as the polarization direction made an angle of 45° with respect to the incident plane of the FSFLC film. The transmitted light was detected by a photodiode after passing through an analyzer. The analyzer and the polarizer crossed each other.

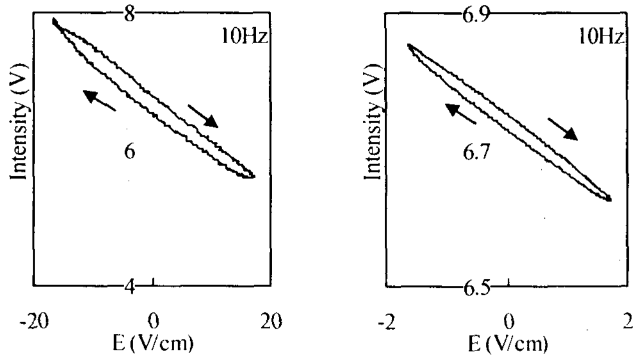
The film thickness was determined by an evaluation of the phase shift in the FSFLC film due to a birefringence. For the determination of the thickness, principal refractive indices of CS-1029 was required but have not yet been measured, and so we used the common values for FLC of 1.49 and 1.65 for ordinary and extraordinary light, respectively. The thickness of the FS film used in this study was about 24 μm.

The transmission light intensity are depending on sign and strength of the applied field , as shown in Fig.2. In this measurement, the applied field was static at each strength, so that the intensity was not trangent. The intensity gradulally change depending on the strength. This electrooptic effect is caused by the deformation of helicoidal structure. This gradual change can not be observe in a thin film which does not have helicoidal structure. [8] This result sugests that a gray scale light valve can be realized utilizing the thick FS fiim.

Figure 3 shows changes of the transmission intensity under the application of dynamic electric field that is sine wave. At low frequency, as shown in Fig.3 (a), the intensity changes according to the characteristic shown in Fig.2 except for small loop at moments of polarity reversals. This loop indicates that there is an extremely slow molecular dynamics at the moments of the polarity reversal. At the high frequency, the loop is expanded along the characteristic curve, as shown in Fig.3 (b) and (c). When amplitude of the applied field is decreased, a peak-to-peak (pk-pk) value of the response becomes small, as shown in Fig.3 (c), (d) and (e).



(a) E = 167 V/cm. (b) E = 167 V/cm. (c) E = 167 V/cm.



(d) E = 16.7 V/cm. (e) E = 1.67 V/cm.

Fig.3 The intensity of the light under the application of the dynamic electric field: $E \sin\omega t$.

Figure 4 shows frequency dependencies of the pk-pk values concerning $167\sin\omega t$ (V/cm) and $1.67\sin\omega t$ (V/cm). The pk-pk values are almost constant, but start to decay above 500 Hz.[9] Figure 5 shows the field dependencies of the pk-pk values. Differences between the transmission intensity at counter polarity of the static field shown in Fig.2 are also shown in Fig.5. They are proportional to the amplitude of the applied field E in a range between 0.33 V/cm and 167 V/cm. These properties can not be observed in the thin film that does not have the helicoidal structure.

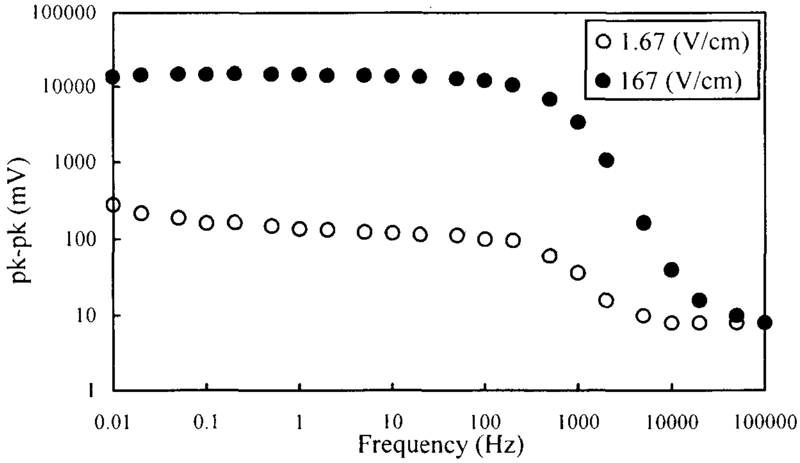


Fig.4 Frequency dependencies of the pk-pk values.

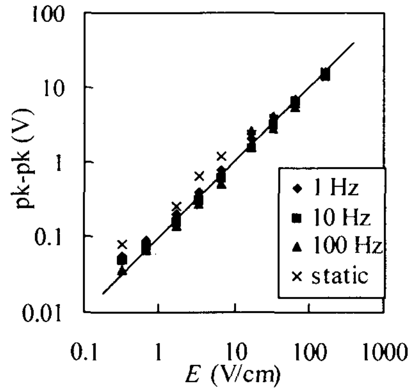


Fig.5 Field dependencies of the pk-pk values. Applied field was $E\sin\omega t$. The solid line is proportional to the E.

This work can be summarized as follows. (1) The electrooptic effect of the freely suspended ferroelectric liquid crystal films was studied. (2) The characteristic properties of electrooptic effect caused by the deformation of helicoidal structure were observed. (3) The gray scale electrooptic effect which was depending on the strength and signe of the applied field was observed. (4) The pk-pk value of the transmission intensity under the alternating applied field was proportional to the amplitude of the applied field.

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